MACRO- AND MICROSCOPIC STRUCTURE OF THE ROOT OF *CERATOPTERIS PTERIDOIDES* (HOOK.) HIERON.*

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ABSTRACT

The structure of the root of *C. pteridoides* is almost identical with that of *C. tholictroides*, except in the former species the root shows somewhat less orderliness regarding the arrangement of lateral roots. The occurrence of lateral roots is related to the leaf rather than to the root apical cell. Since the new immediate lateral derivative of the apical cell is always produced beside the oldest cell of the three surrounding cells cut off from the three side faces of the apical cell, it is suggested that the regular formation of the new cells in cyclic order from the apical cell is dependent on the simultaneous presence of its surrounding cells of different ages. Since the walls of the rootcap are always thicker than those of the meristematic cells in the root tip, it is thought that this relative inflexible rootcap may act as a mould, contributing to nance of a definite form of the root tip by casting a mass of flexible cells of the the mainteapical meristem in it. The formation of rootcap is found essential in the construction of root proper in this fern.

INTRODUCTION

Ceratopteris pteridoides (Hook.) Hieron. is an aquatic leptosporangiate fern which belongs to the family Parkeriaceae. Although this species has been known to botanists since 1825 when W. J. Hooker first described it (Hooker, 1825; Hieronymous, 1905; Benedict, 1909; DeVol, 1957; Cronquist, 1961; Chiang and Chiang, 1962, Momose, 1964), it is not so common as *C. thalictroides* (L.) Brongn. presumably because of its restricted distribution. *C. pteridoides* has been collected only from a few places in America and Asia (DeVol, 1957, 1967), whereas *C. thalictroides* is known to be distributed throughout the world (Smith, 1955). The study of *C. pteridoides* has not yet gotten beyond the field of taxonomy.

MATERIALS AND METHODS

The plants which the author studied were originally collected in the Aquarium at the Taipei Zoo by Professor C. E. DeVol* and myself in 1960, and was identified by DeVol as *Ceratopteris pteridoides* (Hook.) Hieron. (DeVol, 1967). The plants have been kept growing in the tank of the greenhouse in the Department of Botany, National Taiwan University since its collection. It is these plants which the author has used in the present observation. For anatomical study, the roots of 5~10 cm in length were harvested in early October, 1967 and were immediately fixed in Craf III (Sass,

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1958). Some supplemental materials were collected and fixed in the August of 1969. After dehydration with a tertiary butanol series, the materials were embedded in paraffin. Serial sections were made in both transverse and longitudinal planes at a thickness of 8 μ and stained with safranin and fast green (Johansen, 1940).

OBSERVATIONS

Macroscopic nature of the root.

The sporophyte of *C. pteridoides* has the root, one of the essential organs for the life of this fern, as a part of the plant body (Fig. 1b). When the plant is free floating, the root grows downward into the water (Fig. 1a). If an individual sporophyte is floating singly on the water in a transparent aquarium in which the light comes from all directions the roots of this plant soon become entangled with filamentous algae (Fig. 1a). When these epiphytic algae grow thick around the roots, the roots are not able to grow straight. The tip of the root is then curved (Fig. 1a), and consequently the growth of the entire plant is seriously restricted. In a large greenhouse tank, the plants grow together, forming a colony, and thus most of the sunlight under the water is shut out by their broad leaves which are spreading on the surface of water. The growth of this species in nature, therefore, presumably depends on "togetherness". The plant grows well in a laboratory if the roots are adequately sheltered. If the water is shallow and the tip of the root reaches the soil, it grows continuously downward into the soil, anchoring the plant body and thus avoiding the harmful influence of epiphytic algae.

The roots of this plant develop from the abaxial side of the base of the stipe and thus they are adventitious roots (Fig. 1b). The entire mass of roots of a single sporophyte consists of several distinguishable groups of roots, each of which arises from a leaf of the sporophyte. All roots of an individual petiole occur at about the same time while the leaf is still circinate or very young (Fig. 1c), *i.e.*, they are about the same age. Successively older leaves of an individual sporophyte have successively older groups of roots. The number of roots produced on each stipe is variable. In one plant, the root number per stipe varies from 8 to 16 (Table 1). Roughly, root number is related to leaf size; the larger leaf bears more roots on its petiole (Table 1). The number of roots may be more than 16. In one leaf, 17 roots

Figs. 1a-1f. Photographs showing external features of the roots. —Fig. 1a. A mass of roots of an individual plant which was grown in water in a transparent aquarium, showing that the roots were attached with epiphytic algae, ×1. —Fig. 1b. A photograph showing the emergence of new roots on the youngest leaf and the older roots on the older leaves, ×1.5. —Fig. 1c. The growing roots of an individual leaf which is still circinate, ×1. —Fig. 1d. An individual root showing its lateral roots and root hairs, ×1.3. Note that two lateral roots may occur at the same place on the parent root. —Fig. 1e. A photograph showing a portion of an adventitious root and its secondary roots and tertiary roots, ×1.5. —Fig. 1f. A photograph magnified from a portion of Fig. 1e, showing two tertiary roots occurring at the same place on the secondary root.

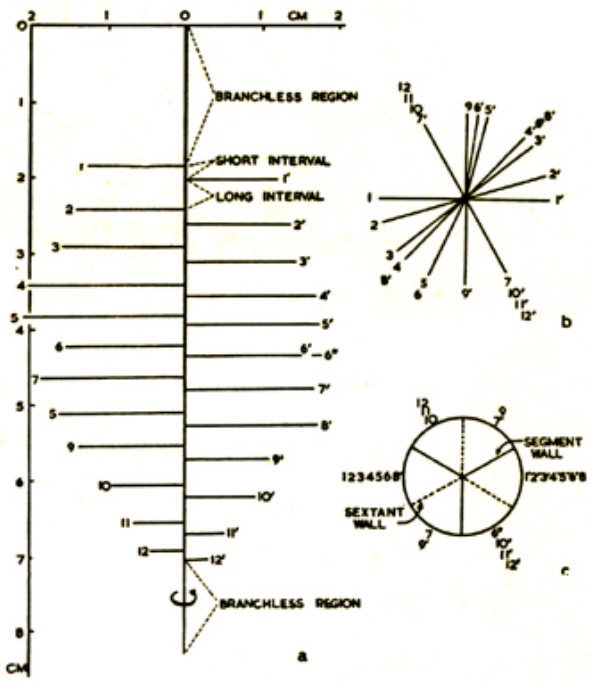
Fig. 1.

Table 1. Correlation between root number and leaf length in an individual sporophyte

Age of leaves	Leaf length (cm)	Root number
Younger	20 (still growing	16
↑	19~24	12~13
Older	18~22	8~9

were observed (Fig. 1c). At sporeling stage, the leaf is very small and one leaf has only one root (Chiang and Chiang, 1962). Most of the adventitious roots, especially the thicker or larger ones, produce lateral or branch roots (Figs. 1a, 1e). Small, thin roots are occasionally branchless. Branches of the first order (secondary roots) are common in this fern (Fig. 1a). Some large roots may have root branches of the second order (tertiary roots) (Fig. 1e). The branch of the third and higher orders have not been observed. All of the roots are cylindric, tapering slightly towards the tip (Fig. 1c). The roots which are borne on the same stipe vary in thickness (Fig. 1c). The thickest root seldom exceeds 2 mm in diameter. The thicker roots are usually longer. Branch roots are always thinner and shorter than the parent root. Although the roots differ slightly in thickness, they are numerous, long and slender and thus the entire mass of roots of an individual plant appears as a fibrous root system.

Typically, the secondary roots are regularly arranged. They occur in two vertical rows which are opposite each other on the parent root. They are alternately arranged. Two adjoining lateral roots on the opposite sides of the main root may constitute a short or a long interval (Figs. 2, 4, 5). The short and long intervals are alternately arranged. In the mature region, the length of the long interval is about twice that of its adjacent short interval. The interval between two adjoining lateral roots in the same vertical row is equal to a short interval plus a long interval. If the occurrence of lateral roots are illustrated to be perpendicular to the main root at their sites of occurrence, the alternate arrangement of long and short intervals, or the pairing of lateral roots, appears to be remarkably clear (Fig. 2a). Frequently, the roots with irregularly arranged lateral roots are found. In some roots, the arrangement of short and long intervals are regular, but the lateral roots are not in the same vertical rows (Figs. 2b, 2c). Evidently, the lateral roots may occur in any sextant. Occasionally, two lateral roots occur at the same place on the parent root (Figs. 1d, 1e, 1f, 2, 3). In this case, two lateral roots are found occurring respectively in the two sextants of the same segment under the microscope (Chiang, unpublished). Secondary roots always grow obliquely downward, making an angle of about 60° with the main root.



Figs. 2a-2c. Arrangement of lateral roots on a main root. —Fig. 2a. An adventitious root showing the alternate occurrence of short and long intervals and branchless regions, ×1. Lateral roots are depicted to be at right angles to the main root in order to make it easier to recognize that they are arranged in pairs. —Fig. 2b. The axial view (from tip to base) of the root depicted in Fig. 2a, showing the occurrence of lateral roots around the main root axis. Note that the main root twists in an anticlockwise direction. —Fig. 2c. A diagrammatic illustration showing the occurrence of lateral roots in each vertical row of the sextant based upon actual observation as depicted Fig. 2b. Broken line indicates the sextant wall. Fig. 2c does not take into account the twisting of the main root.

Both main and lateral roots are always found twisting slightly around their axes. The twisting may be either clockwise or anticlockwise. In one observation, 3 out of 4 roots on the same stipe twisted in clockwise direction, while the other one was anticlickwise. The direction of the twisting of the root may be known, 1) by observing with the naked eye the arrangement of lateral roots on the main root (Fig. 2), 2) by observing the arrangement of epidermal cells under the microscepe, and 3) by observing the segmentation pattern of the root apical cell under the microscope (Fig. 10).

In a typical mature root, usually two prominent branchless regions, one at the tip and the other at the base of the root, are recognizable (Fig. 2a). The occurrence of branchless regions on the main root, however is not always restricted to these two regions. Fig. 3 shows the occurrence of the branchless regions of each root of an individual sporophyte of *C. pteridoides*. All roots of this plant have lateral roots. Some roots have a long branchless region at the base of the root while others have

two branchless regions at both ends of the main root. Sometimes a branchless region occurs at the middle of the main root. It is interesting to note that the roots produced on the same stipe have the branchless regions in the same place on the main root (Fig. 3). Evidently, the occurrence of lateral roots is related to the leaf, its condition of growth, rather than to the root apical cell or root apical meristem.

Studies on some plants in water (31°C at noon) in a greenhouse tank in August showed that the main root grew about 8 mm in length per day and produces 1.5 pairs of lateral roots per day during its growing period.

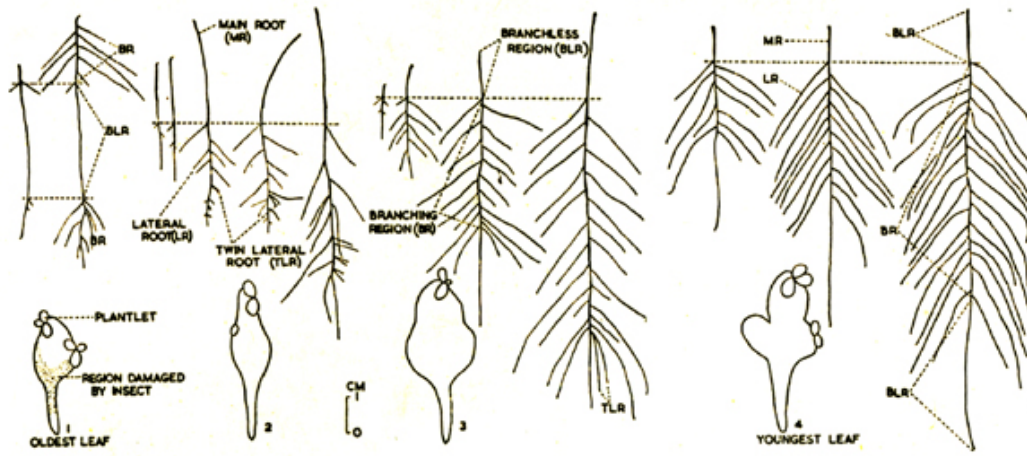


Fig. 3. The occurrence of branching regions and branchless regions on the adventitious roots produced on the stipe base of the leaves of an individual sporophyte, ×0.5. Note that the location of the branchless regions of all roots produced on the same leaf are correlated with each other.

Microscopic structure of the root.

Root proper. As in *C. thalictroides*, the root tip of *C. pteridoides* consists of two easily distinguishable parts, namely the root proper and the rootcap (Figs. 4, 5). A conspicuous tetrahedral cell known as root apical cell is always present at the extreme tip of the root proper of both main and branch root (Figs. 4, 5, 6). Its three sides or lateral faces are approximately triangular and more or less flat, whereas its foreward or distal face is round and hemispherical or watch-glass-shaped (Fig. 6). The diameter of the distal face is about 50 μ, whereas the height from the distal face to the tip of the apical cell is about 30 μ (Fig. 6). The root apical cell has a conspicuous spherical nucleus of about 15 μ in diameter. Several nucleoli are seen in it when it is at the interphase stage. The root apical cell divides along its four faces, producing the root proper segments from its three side faces, and the rootcap segments from its distal face. The distal face always divides less frequently than the side faces, resulting in a cap segment with thicker walls. Typically, every

10th division of the apical cell occurs along the distal face. By regular anticlinal divisions in a cyclic order the root proper segments are successively cut off from the three side faces of the apical cell. It may be clockwise in one root but may be anticlockwise in another. The new root proper segment is always produced next to the oldest segment of the three side segments surrounding the apical cell, *i. e.*, the new wall of the apical cell is formed parallel to the oldest side wall of the apical cell. The root apical cell is therefore always surrounded by the three youngest (or newest) segment walls of the root proper and one youngest segment wall of the rootcap. The segments of root proper and the segments of rootcap are respectively the constituting units of root proper and rootcap. The root of this fern consists of very regular repetitions of these segments derived from the apical cell. The segment of root proper is surrounded by five segment walls, two transverse, two radial, and one periclinal. All of these walls are derived from the apical cell, *i. e.*, the radial and transverse segment walls of the root proper segment are originally the lateral wall or a part of the lateral wall of the apical cell, wheresa

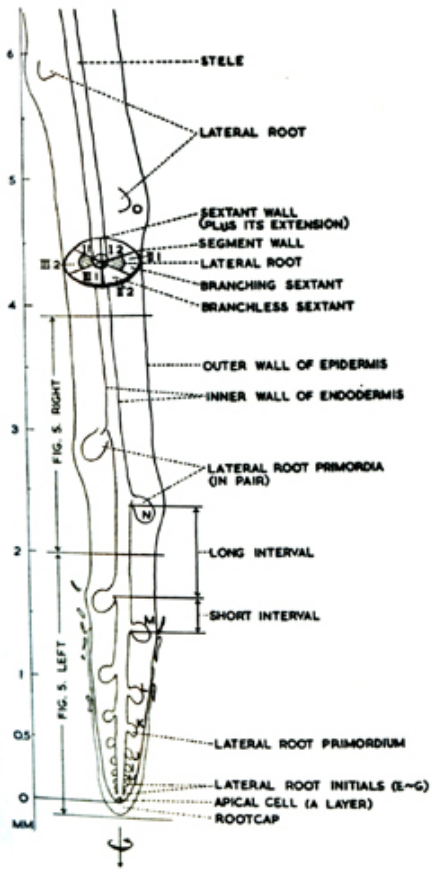
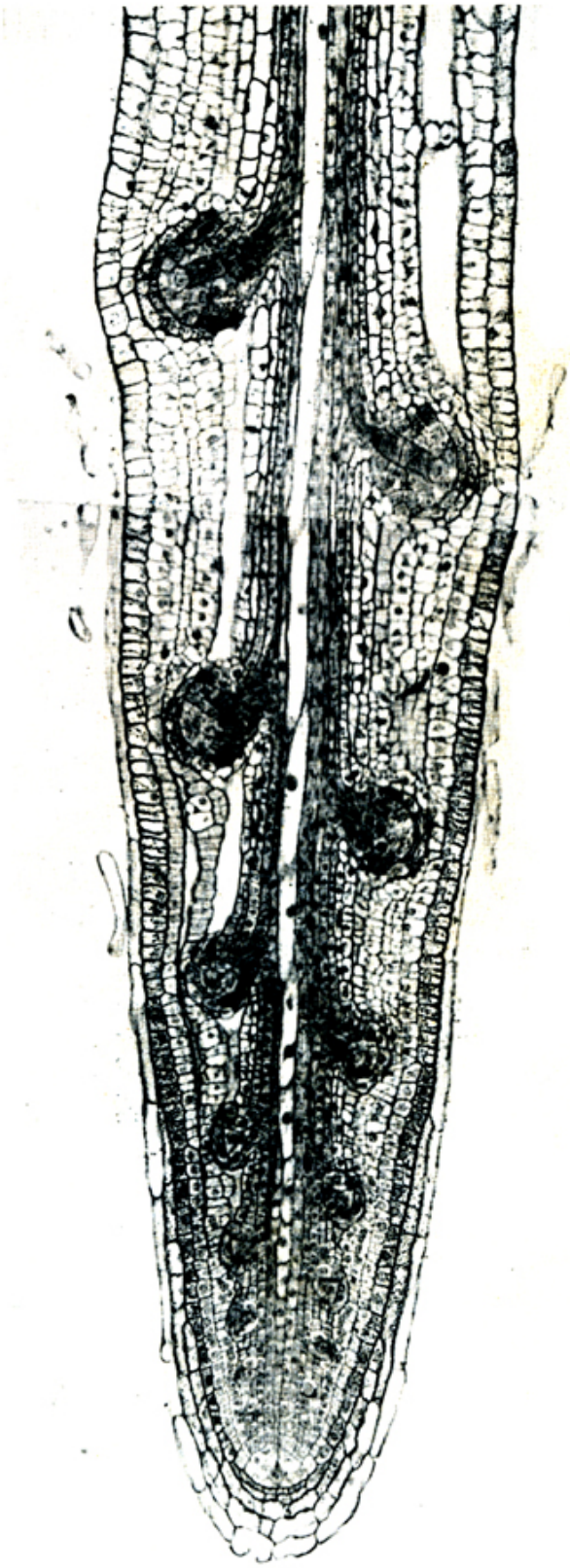
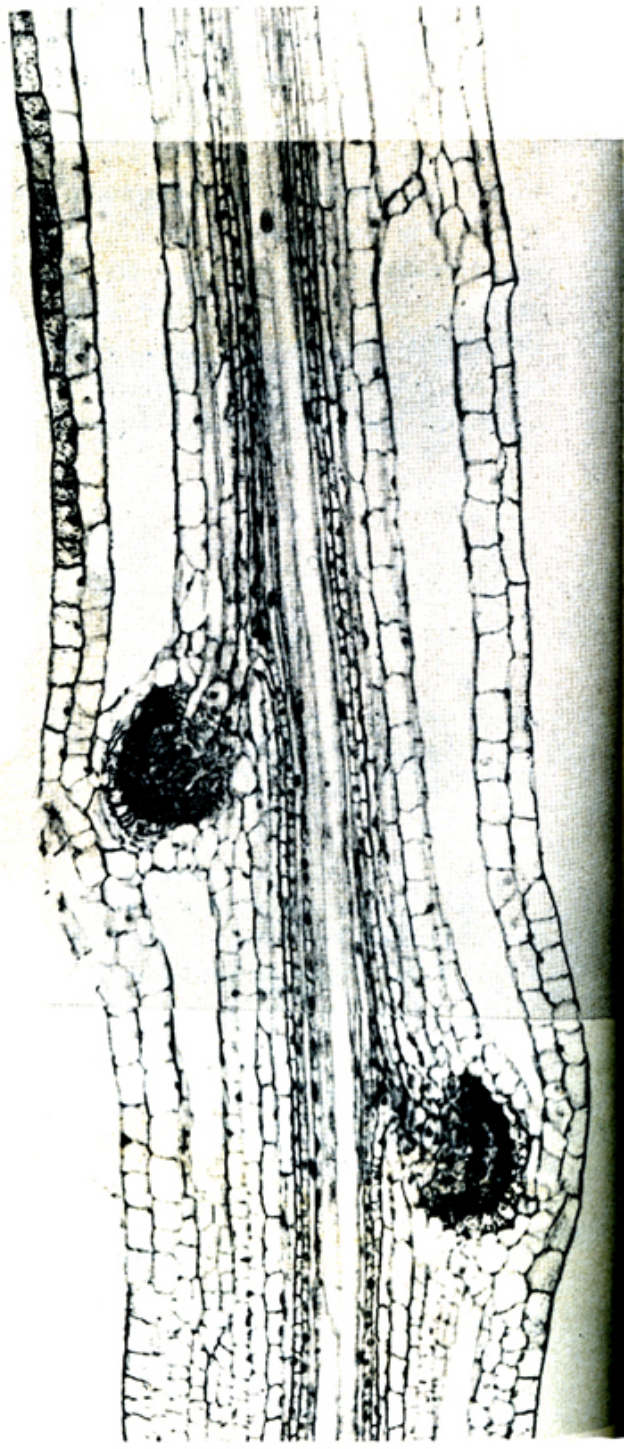


Fig. 4. A median longitudinal section (through two vertical rows of branching sextants) of an adventitious root showing the regular occurrence of lateral root initials and lateral root primordia in pairs in two opposite rows, ×16.5. The region above 4 mm is not cut exactly through the branching sextants. The letters A to O indicate the segment layers from which the lateral roots arise. See Figs. 5 and 6 for the detailed microscopic structures of this root.

Fig. 5.





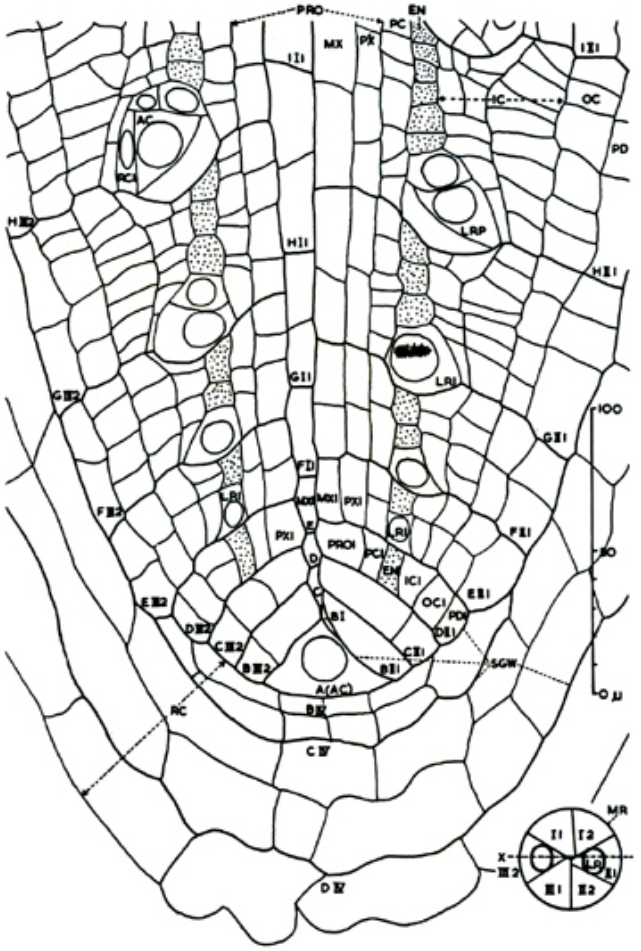


Fig. 6. A camera lucida drawing of a median longitudinal section of the root apical meristem of an adventitious root through branching sextants, showing the apical segmentation and origin of lateral root initials, ×380. Successively older segments or layers are labelled with B, C, D, ... respectively. The segments from the same cutting face of the apical cell have the same Roman numerals. Among the three segments labelled with the same alphabet, segment I is the youngest, whereas II and III are successively older segments. The sextant layers of the same vertical row have the same Arabic numerals, 1 or 2. The sextant 1 is younger than the sextant 2 in the same segment. The apical cell (AC), lateral root initials (LRI) and lateral root primordia (LRP) are indicated by nuclei. EN, endodermis (stippled); ENI, endodermis initial; IC, inner cortex; ICI, inner cortex initial; LR, lateral root; MR, main root; MX, metaxylem; MXI, metaxylem initial; OC, outer cortex; OCI, outer cortex initial; PC, pericycle; PCI, preicycle initial; PD, protoderm; PDI, protoderm initial; PRO, procambium; PROI, procambium initial; PX, protoxylem; PXI, protoxylem initial; RC, rootcap; RCI, rootcap initial; SGW, segment wall; SXW, sextant wall; X, the plane of the section. The same symbols are used in successive figures.

Fig. 5. A photograph of the median longitudinal section of an adventitious root, showing the internal structure, ×100. Note that lateral root initials and primordia are arranged in pairs in two opposite rows. For detail explanation, see Fig. 4 which is a diagrammatic representation of this root.

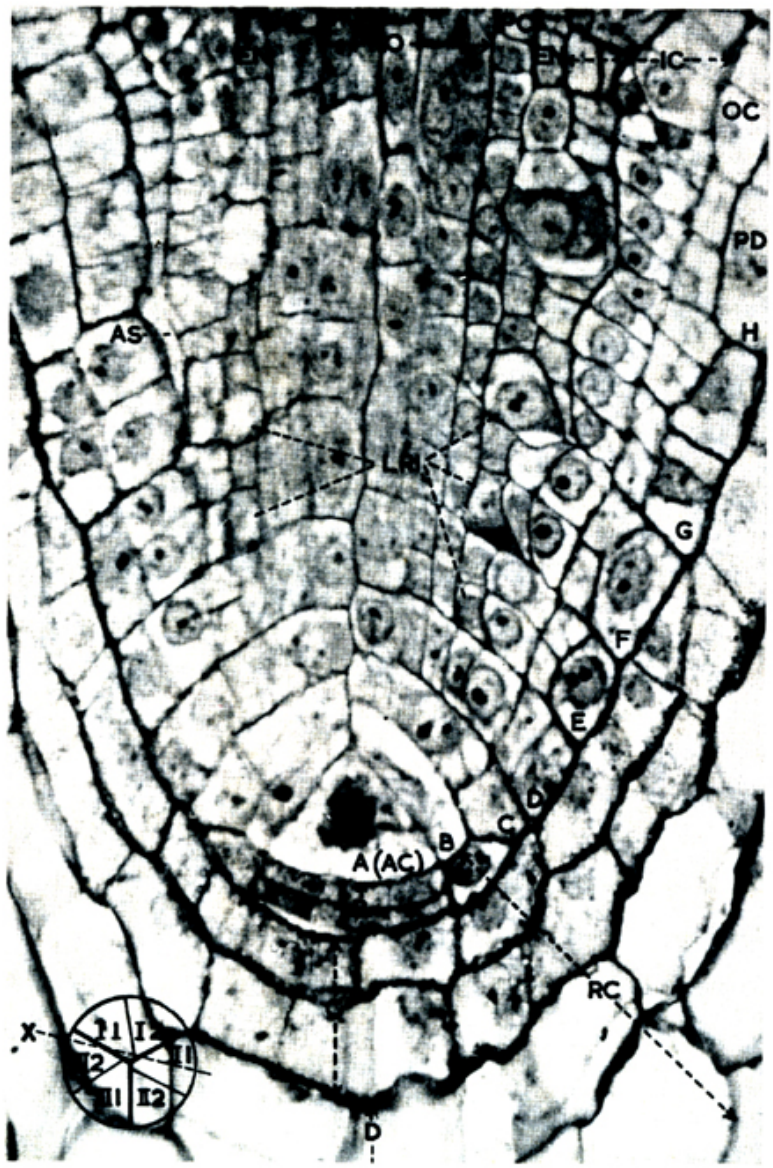
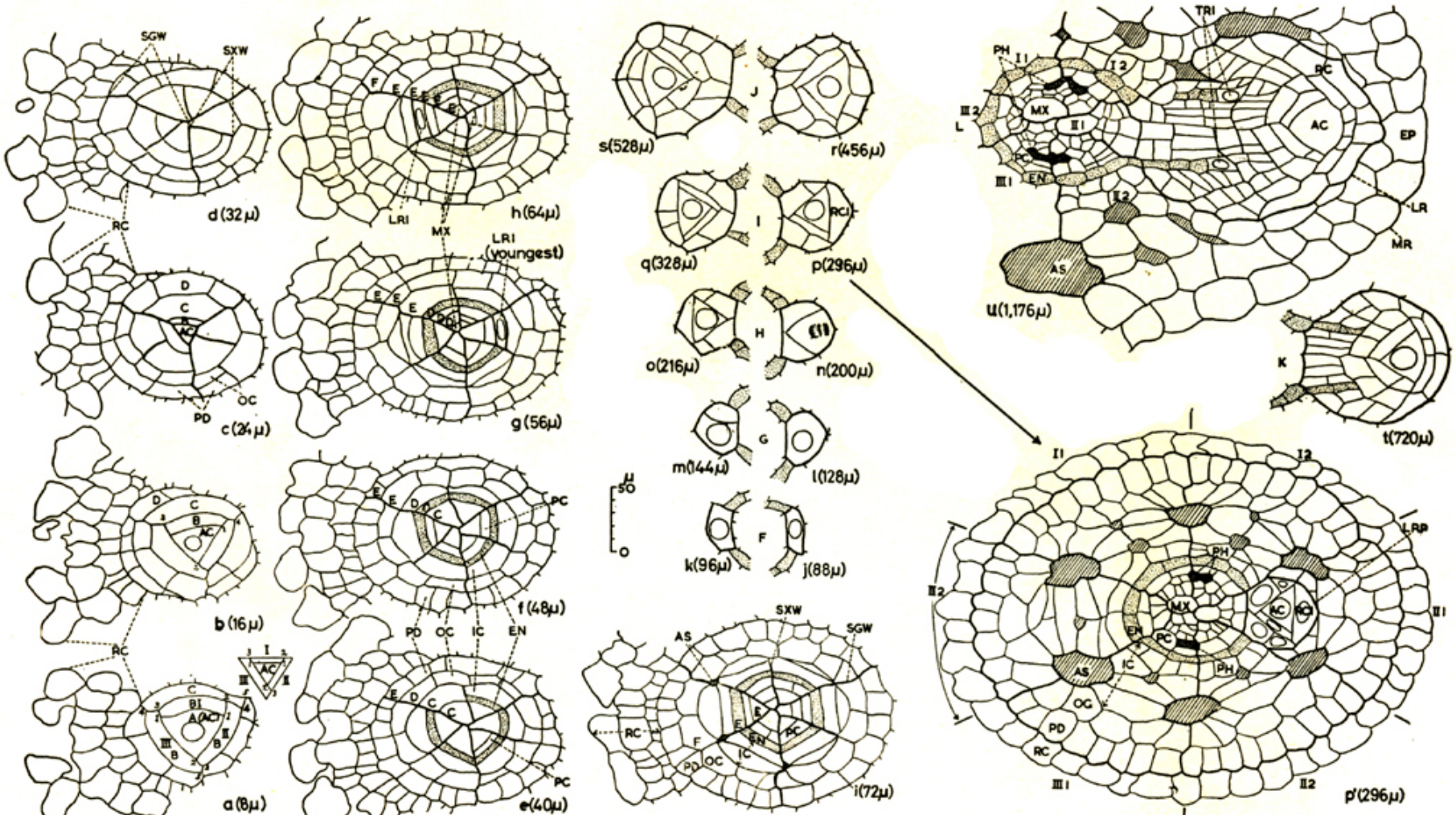


Fig. 7. A microphotograph of root apical meristem, ×514.
For abbreviations see Fig. 6.

the periclinal segment wall (the outer wall of protoderm) is originally a part of the distal wall of the apical cell. The root apical cell of this fern is recognized as a true or indeterminate meristematic cell since it maintains its ability of cell division over a long period of time without changing its original form and size, *i.e.*, without maturing or differentiating. This nature of the root apical cell differs greatly from that of its derivatives or segments which are determinate.

Successively older segment layers from the apical cell are designated by letters of the alphabet in order (Fig. 6). The immediate derivative or segment (B layer) cut off from the lateral face of the apical cell (A layer) of the main root is a flat, fan-shaped cell. The first division of this cell occurs periclinally, forming two cells (B layer). These two cells are actually about equal in volume, but in a longitudinal section the outer cell is smaller than the inner one. The outer cell then divides by two radial walls into three cells while the inner cell divides by a radial or sextant wall, which is laid down between the first periclinal wall at its middle and the younger segment wall slightly away from the contact angle of the segment walls, into two cells. The second periclinal wall is laid down in each of these two cells between sextant wall and segment wall, resulting in a segment with three periclinal layers (C layer). Each cell of these layers then divides by a periclinal wall to become a segment with six periclinal layers (D layer). They are respectively (from the outside) the initial layer of protoderm, outer cortex, inner cortex, endodermis, pericycle and procambium and give rise to the mature tissues respectively by radial and transverse divisions except that of the inner cortex and procambium which also divides by a few periclinal divisions. Since the protoderm, outer cortex, endodermis and pericycle are devoid of periclinal division (there are only few exceptions), they remain uniseriate. The root remains slender because it has only restricted periclinal divisions in the apical meristem as well as in the mature tissue. The description up to this point, necessitates the numbering of each sextant of each layer (Figs. 6, 7, 8). The segments from the same cutting face of the apical cell have the same Roman numerals, I, II or III. The sextant is represented by Arabic numerals, 1 or 2. For example, the first (or younger) sextant of the second segment of E layer is represented as E–II–1 (or E II 1). This is a sextant with a lateral root primordium in a root presented in Fig. 6. Protoxylem initials occur in the D–III–2 and E–II–1 layers (Figs. 6, 8). Two metaxylem initials are found occurring in E–I–1 and E–II–1 respectively (Figs. 6, 8). The first two phloem cells occur in G–I–2 and G–III–1 respectively, that is about 100 μ from the apical cell (Fig. 9a). These two phloem cells are opposite each other and are respectively cut off from the pericycle by a periclinal wall. The next phloem cells occur in I–1 and II–2 (Fig. 8u).

The lateral root initial originates in the meristematic endodermis or "proto"-endodermis in the apical meristem of the parent root (Fig. 6). In a typical root, lateral roots occur in two vertical sextant rows, namely II–1 and III–2, which are opposite each other. Only one lateral root is found occurring in each branching sextant at its base. The initial of youngest lateral root in each row of a main root is found occurring in the E layer, namely E–II–1 and E–III–2 (Figs. 6, 8). As seen in a radial section, the young lateral root initial is boot-shaped, pointing its toe in a centrifugal direction. As the lateral initial grows it increases in size by pushing its outer wall toward the cortex and its basal wall obliquely downwards. The



Figs. 8a-8u. Camera lucida drawings of transverse sections of a root tip showing apical segmentation, early development of various root tissues, and successive stages of development of lateral roots, ×210. The micron in ( ) indicates the distance of the section from the base of the apical cell. j, l, n, p, r, t, and u are those initials and primordia occurring in II-1, whereas k, m, o, q, and s occur in III-2 and are paired with j, l, n, p, and r respectively. The Arabic numerals in Fig. 8a indicate the sequence of wall formation. AS, air space or air duct; EP, epidermis; PH, phloem; TRI, tertiary root initial; for other symbols, see Fig. 1.

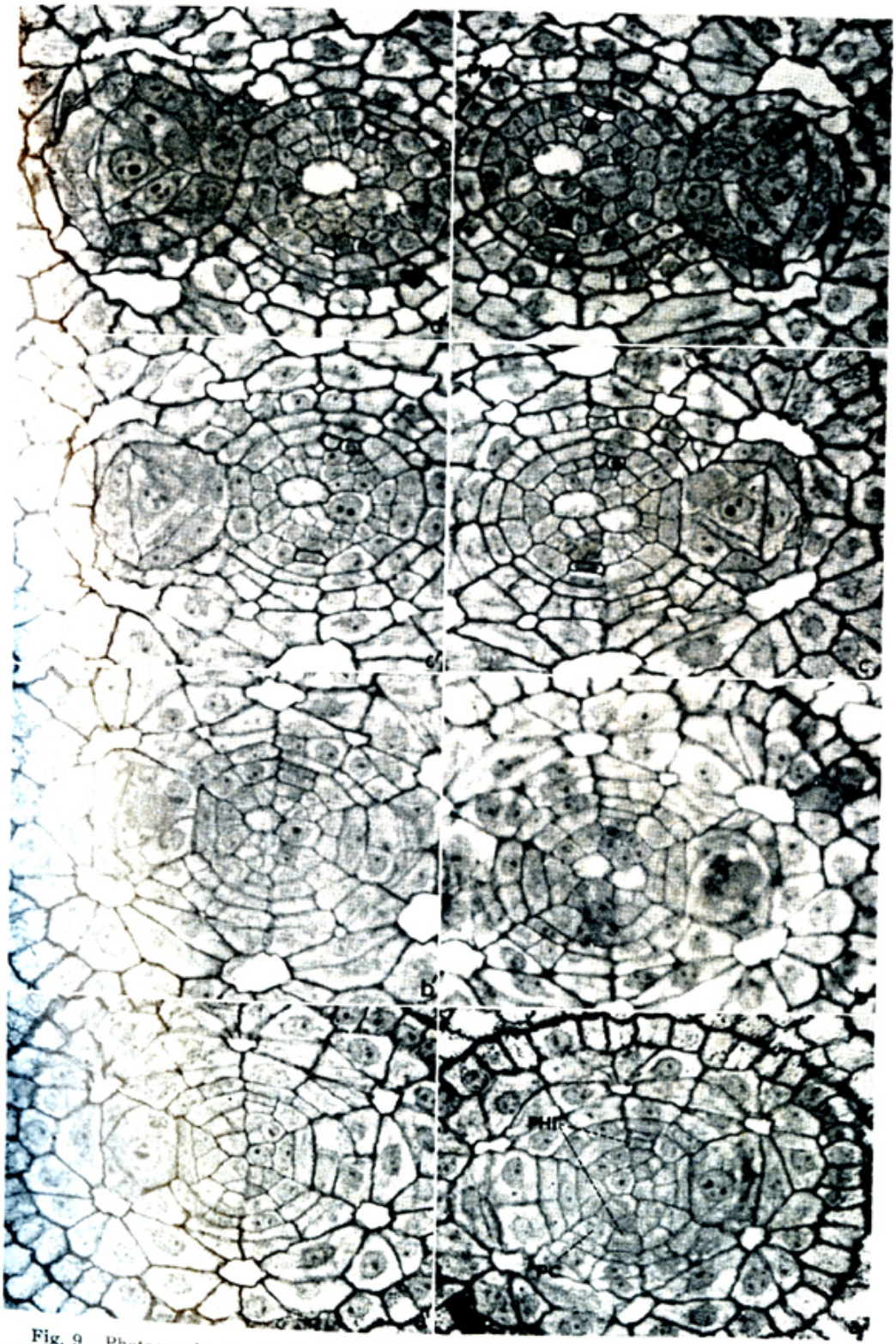


Fig. 9. Photographs of the transverse sections of an adventitious root through lateral root primordia, ×330. These sections were used in the preparation of some drawings in Figs. 8l-8s. PH, phloem; PHI, phloem initial; PC, pericycle.

extremely large size of the nucleus of the lateral root initial is probably caused by one or more endomitotic divisions (Fig. 11g). The first wall of the lateral root initial is approximately horizontal (Fig. 6). It cuts the initial into two cells of unequal size in the G layer. The upper or smaller cell with a somewhat faint cytoplasm is the first segment of the root proper of the lateral root (Fig. 7). Followed by two successive oblique divisions, the second and third segments of the root proper are cut off from the lower or larger cell with a dense cytoplasm, resulting in a new tetrahedral apical cell of the lateral root surrounded by three lateral segment walls and one forward wall facing outward. The fourth division occurs at the foreface of this new apical cell, cutting off the first rootcap initial of the lateral root. The growth direction of lateral root is related to the position of its first segment which is always opposite to the tip of the main root. The twisting of lateral root is decided by the position of the second segment of the lateral root. Further segmentation of the lateral root primordium is regular and similar to that of the main root (Fig. 10). The second cap initial is cut off from the lateral root apical cell by the 14th segment wall of the lateral root. (Figs. 10c, 10d).

The first differentiated tissue appearing in the lateral root primordium is the endodermis, which is a thin, flat cell of about 3 μ in thickness or about 1/3 that of the main root (Fig. 10b). It joins to that of the main root forming a continuous layer (Fig. 10b). Following the differentiation of the endodermis the connection of the pericycle between the lateral root and main root occurs. Before connection, several pericyclic cells of the main root, which adjoin the lateral root divide periclinally or obliquely (Fig. 10e). The pericycle of the lateral root then joins to that of the main root to form a continuous layer. The remaining pericyclic cells adjoining to the lateral root transfer to become the procambium which connects the procambium of the lateral root to that of the main root (Fig. 10e).

Just as in *C. thalictroides* (Chiang, 1967). The root proper of *C. pteridoides* consists of three vertical rows of segment layers which are produced orderly from the three side faces of the apical cell. Each segment layer has two sextants delimited by a sextant wall plus its extension. In a typical root, only two definite sextant rows which occur respectively in two definite segment rows are involved in lateral root formation. Each branching sextant produces only one lateral root at its base (Figs. 6, 7). These regular internal occurrences result in regular external arrangement of the lateral root on a main root. This stituation was stated by Chiang (1967) as follows: "external morphology reflects internal structure, and *vice versa*". Each lateral root of one row is located one third of an interval down or two thirds up from each lateral root in the opposite row, resulting in the short and long intervals which are alternately arranged on the main root (Fig. 2). Therefore, after emergence, lateral roots are seen to be arranged in pairs, two lateral roots of each pair separated by a short interval, and two successive pairs of lateral roots separated by

a long interval. At maturity, the long interval is about twice that of the short interval and the length between two adjoining lateral roots in the same vertical row is about 3 times that of a short interval. The latter is equal to the length of a segment. Since the occurrence of a long interval is the result of the occurrence of one branchless segment while the occurrence of a short interval indicates the successive occurrence of two branching segments, it is possible to know how many divisions occurred previously in the root apical cell simply by counting the number of lateral roots produced on the parent root during a known period of growth. By this simple method, Chiang (1967) was able to determine the nuclear cycle of the root apical cell in *C. thalictroides* in its grand period of growth as about 5 hours in duration. As described earlier in this paper, in a rapidly growing root of *C. pteridoides*, 1.5 pairs of lateral roots were produced per day. This is the result of 1.5×3 or 4.5 divisions occurring along the three side faces of the root apical cell plus 1.5/3 or 0.5 division occurring at the base of the apical cell. The nuclear cycle of the root apical cell of *C. pteridoides* is therefore 24/(4.5+0.5) or 4.8 hours or approximately 5 hours in duration (For details, see Chiang, 1967).

Rootcap. The dome-shaped tip of the root proper of *C. pteridoides* is always closely covered by a dome-shaped cap or rootcap of living parenchyma cells, usually in 4 to 6 layers of about 100 μ in thickness at the region in front of the apical cell and in successively fewer layers at the regions away from the tip of the cap (Fig. 5). The typical rootcap is about 1.5 mm in length and 0.5 mm in diameter at the middle of the cap. The inner cells of the rootcap at the region in front of the apical cell are smaller and meristematic, whereas the outer cells are larger and highly vacuolated (Figs. 5, 6, 7). The cells of rootcap are arch-shaped in the median longitudinal section. Those cells away from the tip of the cap are very much elongated (Fig. 6). A mature rootcap consists of about three distinguishable groups of cells or segments, each of which has arisen from a single rootcap initial or calyptrogen which is cut off from the basal face of the apical cell. The cap initial is lenticular in shape. The older segment, which is cut off earlier, is located on the outer side of the cap, whereas the successively younger segments are located successively nearer to the apical cell. A mature segment of the rootcap always has cells arranged in two layers except in the marginal region where the cells are uniseriate (Fig. 5). In spite of the continued addition of new cells on its inner surface, the rootcap does not change much in its thickness or volume since the oldest cells on the outside are constantly being worn off. The walls, especially the segment walls of the rootcap are older or thicker than those of the meristematic cells of the root proper. This is an inevitable result of the peculiar segmentation pattern of the apical cell. The cap initial is cut off on every 10th division of the apical cell and thus it has a longer period of duration for the growth of its walls in thickness than those of the root proper surrounded by it. It is interesting to note that the

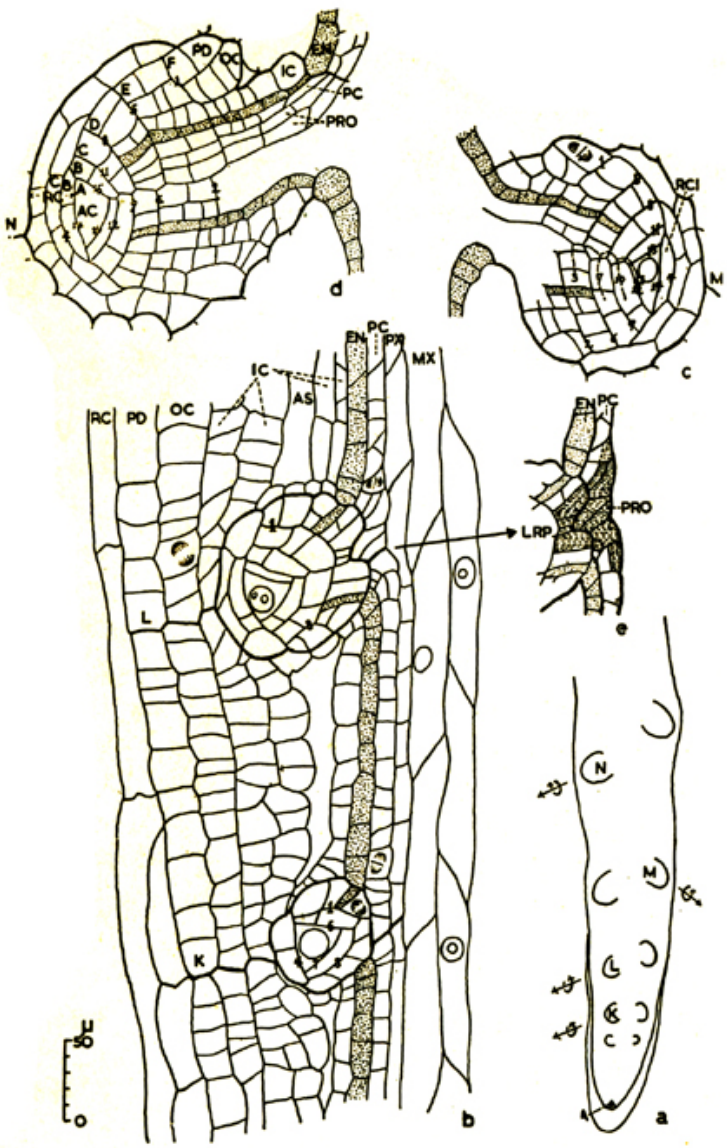


Fig. 10. Camera lucida drawings of the longitudinal median sections of lateral root primordia at various stages of development, showing the connection of tissues between the lateral root primordium and the main root, ×210. —Fig. 10a. A camera lucida drawing showing the location of those primordia depicted in Figs. 10b, 10c, and 10d in the parent root. The direction of twisting is also illustrated. The Arabic numerals indicate the sequence of wall formation. The blank areas in Figs. 10c and 10d are cut through the adjoining plane of two segment rows and therefore in spite of our best efforts with an oil immersion lens we were not able to observe these areas. For symbols, see Figs. 4 and 6.

outer walls of root protoderm (and so of the epidermis) was previously part of the inner wall of calyptrogen; *i.e.*, it was derived from the inner wall of calyptrogen. This is an important finding showing that the rootcap contributes *directly* to the constitution of the root proper. In other words, the formation of rootcap is *essential* in the construction of root proper in this fern. The outer wall of calyptrogen, which was also previously a part of the inner wall of calyptrogen, on the other hand, also grows as the cap grows but finally sloughs off when it is pushed to the outer surface of the cap. Since the walls of the rootcap are always thicker than any other walls of the meristematic cells in the root tip, it is suggested that this relatively inflexible cap composed of thicker walls may act as a sort of mould, contributing to the maintainance of a definite form of the root tip by casting a mass of more or less flexible cells of the apical meristem in it. It is imaginable that a mass of actively growing cells of the apical meristem may exert a considerable inner or tissue pressure against the more or less rigid walls of the cap. The thick wall of the cap may be also favorable to protect the meristem. Some cells of rootcap, protodem and epidermis are found associated with fungal mycelia (Figs. 5, 11f).

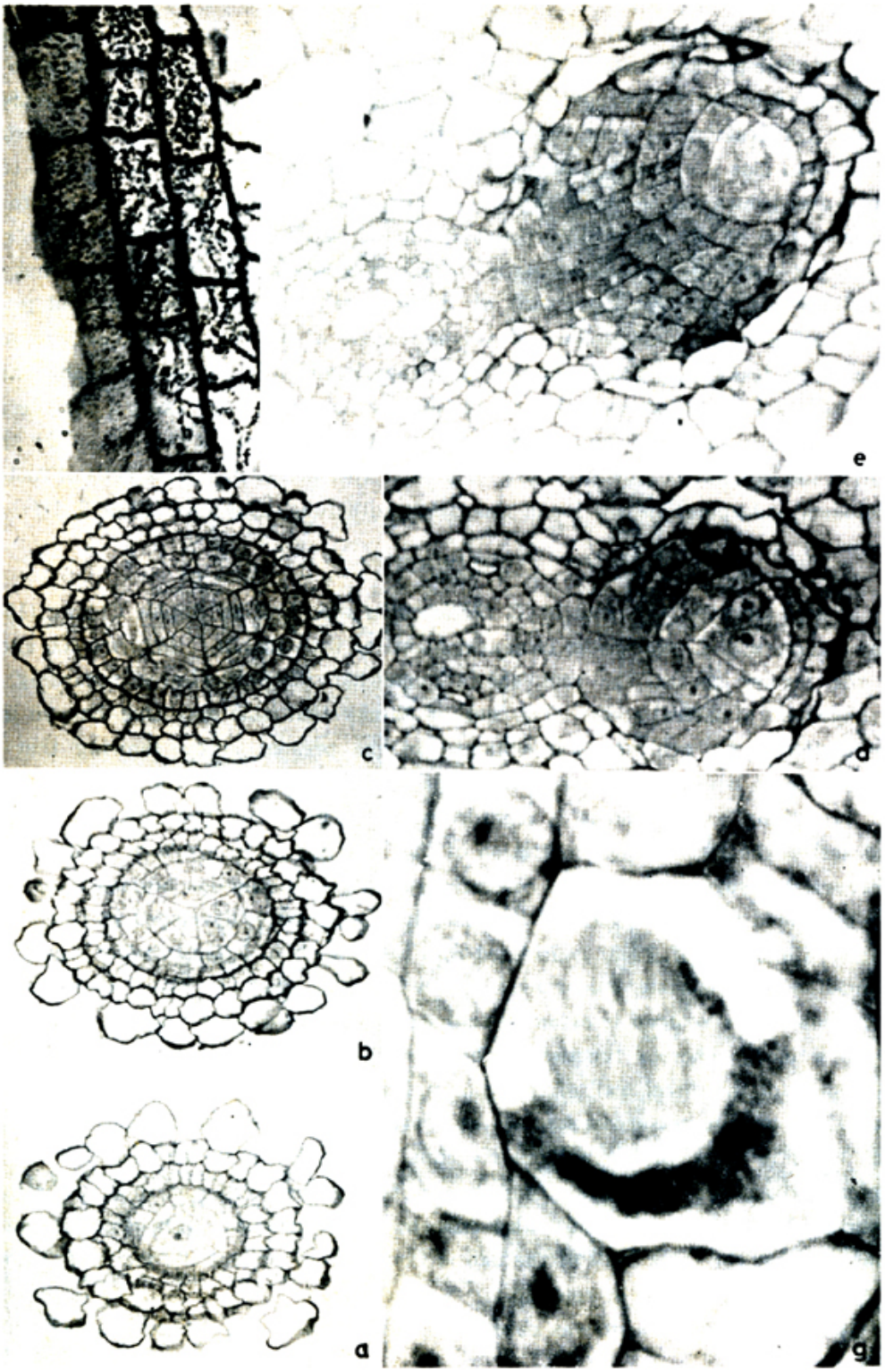
DISCUSSION

A nice work on the root of *C. thalictroides* was done by Sophie Chiang (1967). The structure of *C. pteridoides* is almost identical with that of *C. thalictroides*, except in the former species the root shows somewhat less orderliness regarding the arrangement of lateral roots. The author thinks that this may also happen in *C. thalictroides*. An evidence was obtained in the present study showing that the occurrence of lateral roots is related to the growth condition of the leaf.

Traditionally, the rootcap is regarded as a structure that protects the meristem and assists the root in the penetration of the soil during its growth. Esau (1953), however, has suggested that the rootcap may have other function besides these since she has noted that the rootcaps are usually prominently developed in true water plants. Chiang (1967, 1968) considered that the rootcap of *C. thalictroides* is an acting or modified multiseriate epidermis. In the present work, it was found that the formation of the rootcap is essential to the construction of root proper. This seems to be a more concrete function of the rootcap in *Ceratopteris*. If the growth (or extension) of the distal wall of the root apical cell is indeterminate, the formation of the cap will be not necessary for the construction of the root proper. This case may occur in other plants without rootcaps. It has been known that the walls of rootcap cells are always thicker than those of root proper cells e. g. in *C. thalictroides* (Chiang, 1967, 1968). This is also true in *C. pteridoides*. The present author imagines that the thick wall of the cap is favorable to protect the meristem as well as to maintain the form of root tip.

In the present work, it was observed that the apical cell cuts off a new segment

Fig. 11.



initial from its side face, which is laid it down on the oldest segment of its three surrounding side segments. The first segment wall of the lateral root initial is always laid down on the upper or older tissue of the main root. These results indicate a possibility of the influence of the age of a cell or cells on the formation of a new cell, *i.e.*, the regular cyclic formation of the new cell from the apical cell is dependent on the simultaneous presence of its surrounding cells of different ages.

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Figs. 11a-11g. Photographs of sections which were used in the preparation of the preceding drawings and descriptions. Fig. 11a, Fig. 8a; Fig. 11b, Fig. 8d; Fig. 11c, Fig. 8i; Fig. 11d, Fig. 8t; Fig. 11e, Fig. 8u. Fig. 11a was inadvertently placed on the plate with its upper side turned downard. —Fig. 11f. A tangential section of epidermis, showing the association of fungi with the epidermis, ×400. —Fig. 11g. Endomitosis in a lateral root initial, ×2265.